MINOR STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF CORNELL UNIVERSITY

COMMUNICATED BY E. B. TITCHENER.

XI.— LOCALISATION OF CUTANEOUS IMPRESSIONS BY ARM MOVEMENT WITHOUT PRESSURE UPON THE SKIN.

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This article gives the results of a series of experiments made during the academic year 1895–96. The investigation grew out of the work of Dr. W. B. Pillsbury[1] in the Cornell laboratory during the year 1893–94, and that of Prof. Margaret Washburn[2] published in 1895. The object of this investigation was twofold: (1) To determine as nearly as possible how accurate was the localisation of cutaneous impressions by arm movement *without pressure on the skin;* and (2) to test in this connection the influence of the visual image, which both Mr. Pillsbury and Miss Washburn had found an important factor in cutaneous space judgments. The method used was very similar to that employed by Mr. Pillsbury (E. H. Weber's second method), but differed from it in one important particular. An impression was made on the skin, and the subject was asked to indicate the point touched as accurately as possible by carrying a charcoal point over it, but *pausing in the air above the arm.* In Mr. Pillsbury's work the arm had not only been touched by the subject in the act of localisation, but he had moved about after touching, until he thought he had found the point stimulated.

A. EXPERIMENTS.

Except in the case of one subject, the investigation was restricted to an ellipse on the volar side of each forearm,

[1] "Some Questions of the Cutaneous Sensibility," AMERICAN JOURNAL OF PSYCHOLOGY, VII.

[2] *Ueber den Einfluss von Gesichtsassociationen auf die Raumwahrnehmungen der Haut.* Phil. Stud., XI, 2. Separately: Engelmann, Leipzig, 1895.

beginning just above the wrinkles at the wrist. The major axis extended about 10 cm. in a longitudinal direction, the minor axis being decided by the volar breadth of the subject's forearm. In order to avoid the visualising tendencies produced by operating upon definite and known lines, no permanent division of the area was made; but care was taken that no impression should be in the immediate neighborhood of that just preceding. The arms were taken in alternation. In the earlier part of the work not more than ten experiments were made upon one arm at the same time, and no series for one arm contained at any time more than twenty experiments. With these precautions no disturbance from the after-effects of pressure was noticed. In order that the subjects might not know the arm area operated upon in terms other than those in which they localised, nothing was said to them of the ellipse. Each subject, therefore, in experimenting upon the writer (the exception mentioned above) made the impressions anywhere on the volar side of the forearm, from the first wrinkle at the wrist to a line about 12 cm. above it; the area operated upon being roughly an oblong instead of an ellipse.

During experimentation the subject sat with the arm on which the experiments were made resting on a low table at his side, the elbow being ordinarily a little in front of the trunk and the arm extending along the edge of the table. As it was desirable that there should be no distractions arising from physical discomfort, the exact angle of the arm with the edge of the table was not regulated. There was a variation of 0°-30° approximately. The arm with which the localisation was made either hung by the side or rested on the corresponding knee, when movements in flexion were desired. When movements in extension were tried, as was the case in a few experiments, the arm was held against the chest. The eyes were closed or open, as the experiment required. As has been said, the experimenter touched the arm with a charcoal point; the reactor indicated the point on the skin touched by carrying another charcoal point as nearly as possible over it, but not purposely touching the skin,—thus cutting off the normal ending of the localising movement.[1] The experimenter then dropped a perpendicular from the charcoal point in the subject's hand to the skin, and determined the amount of the localisation error by the aid of a millimetre scale. The charcoal point with which the skin was touched was kept one millimetre in diameter. As in Mr. Pillsbury's experiments, the directions were divided into eight groups

[1]Wundt, "Human and Animal Psychology," pp. 139, 140.

for convenience of record: right (R), left (L), peripheral or towards the wrist (P), central or towards the elbow (C), and the directions midway between these: L P, R P, L C and R C. The subjects were Messrs. Pillsbury (*Py.*), Manahan (*Mn.*), Moyer (*Mr.*) and Miss Parrish (*Ph.*), the latter being experimented upon by all the other reactors.

Since, in our experiments, no definite divisions of the area operated upon were made, and it was desirable to have a method similar to that of Mr. Pillsbury for purposes of comparison, we have chosen the general form of Table I of his work.[1] We have given, however, in the same Table, not only the average magnitude, but the number of displacements in any particular direction, and have separated the experiments on the right and left arms. We have introduced, also, ratios between the *number* of central and peripheral displacements as well as between the average *values* of these. The same thing has been done with right and left displacements.

As in the investigation out of which this grew, the subjects differed very much in their power of voluntarily controlling visualisation.[2] (1) From careful introspection both in this and previous experimentation, *Py.* thought that he was not able to excite or to shut out the visual image at will. The results obtained from him show no appreciable differences of the averages in the visual and non-visual series. When he attempted to pause in the air just above the stimulated point, he had a strong tendency to touch the arm, and frequently did so,—though he did not move the charcoal point after contact. His localisation was always quite close to the arm; but this was especially true in the series with the eyes open. No constant ratio, however, could be established between the distance above the arm at which the movement concerned in localisation ceased and the amount or direction of cutaneous displacement. Table I shows the results obtained from this subject.

In the experiments tabulated under "Normal," the subject was not instructed in what terms to localise, but was left to his own method, simply being asked to localise as accurately as possible. In the series marked "With Visualisation," he was requested to form as vivid an image of the arm as possible and to localise by means of that. In the series marked "Without Visualisation," he was requested to make a direct attempt to shut out the visual image. In the experiments "With Eyes Open," he looked at the arm as the impression was being made, and then, closing his eyes, attempted to localise.

[1] AMERICAN JOURNAL OF PSYCHOLOGY, VII, 1, p. 46.
[2] AMERICAN JOURNAL OF PSYCHOLOGY, VII, 1, pp. 46 and 47.

TABLE I.

Reactor *Py*. Unit = 1 mm.

	NORMAL. FOUR SERIES, 120 EXP.				WITH VISUALISATION. FOUR SERIES, 140 EXP.				WITHOUT VISUALISATION. FOUR SERIES, 160 EXP.				WITH EYES OPEN. FOUR SERIES, 200 EXP.			
	Right.		Left.		Right.		Left.		Right.		Left.		Right.		Left.	
	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.
Peripheral	9	10.5	10	17.3	14	16.1	8	15.5	22	22.7	27	33.1	26	11.4	28	14.2
Central	2	10			2	8									2	6.5
Right	3	14					3	11	3	11			5	10.3		
Left	3	17	5	10.4	2	11.5	9	16.7	9	16.7	4	12.5	9	10.5	5	13.8
Right Peripheral	7	18.6	11	14.7	17	16.6	2	15	2	15	25	19.5	12	11.6	19	12.9
Left Peripheral	32	23.5	25	18.6	32	15.4	40	26.2	40	26.2	24	22.8	42	17.5	43	17.3
Right Central	2	18.5	1	14	2	14	1	35	1	35			2	6.5		
Left Central	2	7	8	16.7	7	11.7	3	13.3	3	13.6			4	11.3	3	3.6
Ratios of Cent. to Peripheral Displ.	.125	.665	.195	.606	.180	.908	.193	.857	.062	.760			.073	.435	.056	.227
Ratios of Right to Left Displ.	.324	1.075	.363	.628	.227	.722	.463	1.079	.116	1.079	.893	.552	.340	.723	.352	.371

The ratios given in the last line of each table were obtained (*a*) by dividing the *number* of right by the number of left displacements, and (*b*) by dividing the average *values* of displacements to the right by the average values of those to the left. In the line next above the lowest, peripheral and central displacements were also treated in the manner just described. Since in, *e. g.*, the "Right Peripheral" displacements, every displaced point was on the right and also peripheral with regard to the original impression, and a similar thing would be true of all the oblique displacements, these were used twice. "Right Peripheral" was added with "Right," and also with "Peripheral." This, of course, would make the average displacements toward the right or toward the wrist too great; but as the averages were used in the way described only in obtaining the ratios, and as nothing is claimed for these beyond a rough indication of the direction of displacement, the larger values do not appear except as involved in the ratios, and need not be misleading there. The occasional large ratios of right to left average values, particularly observable in the Table of *Mr.* given a little later, are not an indication of greater displacement toward the right, as may easily be seen by dividing the sum of right by the sum of left displacements. The arms indicated in the Tables are in all cases those *on* which the localisation was made.

(2) The subject *Mr.* thought from introspection that he was habitually a strong visualiser, and other work done by him in the laboratory tended to confirm this. In order to shut out the visual image of the arm in the non-visual series, he at first kept a Japanese color-scheme before him, and tried to get an image of that to persist while his eyes were closed. This proved to be a distraction; and he then left himself to the fleeting memory images which happened to be passing, ordinarily seizing upon one at the moment of localisation. He frequently fixed upon the image which was in the forefront of consciousness as his hand was going down in the act of localisation. (It may be noted here that the other subjects thought that when the charcoal point touched the arm the visual image of the part stimulated tended to arise in the mind; but *Mr.* did not notice this tendency, nor was the image of the arm, as in the case of *Py.* and *Ph.*, superposed upon what he was voluntarily visualising.) The results obtained from him show very little difference of average displacement between the non-visual and the visual series with the eyes closed. With open eyes, the average displacements are somewhat smaller. It seems probable that *Mr.* visualised with practically the same degree of vividness in

both the normal and visual series; that he was not as well able as he thought he was to shut out the visual image in the non-visual series; and that in the series with the eyes open the visualising tendency was strongest. The results obtained from him are given in Table II.

(3) The subject *Ph.* substituted another visual image in order to shut out the image of the arm, generally selecting some centrally excited image which harmonised best with the mood of the moment, and fixating that when the signal for the experiment was given. In the intervals between the experiments the attention was turned away from anything connected with the work, and not recalled until the signal was given. Frequently, when there was a very strong tendency to visualise the arm area operated upon, the outer surface of the cheek or the upper surface of the foot was substituted and the impression to be localised was seen on that. The subject was in the habit of voluntarily calling up visual images of colored expanses, and these were frequently seized upon at the moment of localisation. The contact of the charcoal point tended very strongly to arouse the visual image of the area touched, and sometimes, in spite of efforts to the contrary, this image was superposed upon that voluntarily fixated. There were a considerable number of experiments in which the subject was conscious of involuntary visualisation from this sudden superposition or interposition of the image, but the results of those experiments showed no diminution in the amount of displacement. Introspection showed that the intrusion of the visual image of the arm generally took place either simultaneously with the movement necessary for localisation or during the sweep of the arm toward the point touched. This would probably indicate that visualisation took place too late to affect the estimation of the movement. In this case, as in that of the other subjects, no connection could be established between the amount of displacement and the distance above the arm at which the subject usually paused in the act of localisation. See Table III.

(4) The subject *Mn.* made no visual substitution for the arm area. He thought from introspection that he did not visualise at all, but that he localised in terms of movement, shutting out all visualisation with reference to the touch of the charcoal point. It would seem from his introspection that he was able to separate entirely the visual from the organic factor; and the greater amount of displacement in his non-visual series as well as the much smaller displacement in his series with open eyes harmonise with this, and suggest the theory given hereafter of the influence of the purely visual factor. The results will be found in Table IV.

TABLE II.

Reactor *Mr.* Unit = 1 mm.

	Normal. Four Series, 120 Exp.				With Visualisation. Four Series, 140 Exp.				Without Visualisation. Four Series, 140 Exp.				With Eyes Open. Four Series, 190 Exp.			
	Right.		Left.		Right.		Left.		Right.		Left.		Right.		Left.	
	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.
Peripheral	15	23	28	30.9	6	21.4	12	22.4	7	27.1	14	23	7	15.1	34	17.6
Central													7	24		
Right	4	17			5	15.2			5	30	1	5	7	15.6		
Left	2	15			1	15					1	14			6	7
Right Peripheral	23	24	8	32	22	17	2	30	48	29.4	25	25.7	78	20.6	4	12.3
Left Peripheral	16	22.6	24	30.5	15	18.8	46	26	10	40.3	28	24			46	16.6
Right Central					6	7.8							2	25		
Left Central					5	13.3					1	14			45	10.5
Ratios of Cent. to Peripheral Displ.					.409	.372					.014	.192	.105	1.390	.059	.226
Ratios of Right to Left Displ.	1.500	1.090	.333	1.049	1.375	.801	.043	1.153	.827	1.463	.827	.896			.070	.360

TABLE III.

Reactor *Ph.* Unit = 1 mm.

	NORMAL. THIRTEEN SERIES, 470 EXP.				WITH VISUALISATION. ELEVEN SERIES, 440 EXP.				WITHOUT VISUALISATION. NINE SERIES, 360 EXP.				WITH EYES OPEN. TWELVE SERIES, 450 EXP.			
	Right.		Left.		Right.		Left.		Right.		Left.		Right.		Left.	
	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.
Peripheral	46	18.4	77	28	34	21.8	99	23	9	15.6	41	29.7	44	13.8	85	16.3
Central	6	9.3	1	25	10	12.9	2	11			2	16	19	10.9	7	5.6
Right	1	15	1	6			4	15.6	1	7	12	24.8	7	11	6	9.8
Left	41	17.9	30	24	80	16.2	5	11.6	67	43.4	14	22.7	33	12.5	21	11.5
Right Peripheral	15	14.2	11	23.6	11	16	55	22.9	9	24.6	72	39.8	40	12.5	51	17.7
Left Peripheral	105	24.3	114	29	71	21.7	49	19.2	62	42.5	28	33.5	44	15.5	43	13.1
Right Central	6	22	1	31	1	8	1	25	2	14	3	31.3	5	9	4	5.2
Left Central	15	15.6			13	18.2	5	9	20	29	5	26	33	12.2	8	11
Ratios of Cent. to Peripheral Displ.	.166	.827	.009	.694	.213	.657	.039	.691	.369	.529	.070	.711	.445	.791	.108	.461
Ratios of Right to Left Displ.	.136	.885	.090	1.143	.073	.427	1.010	1.596	.075	.380	1.643	1.208	.473	.806	.847	.918

TABLE IV.

Reactor *Mn*. Unit=1 mm.

	Normal. Seven Series, 254 Exp.				With Visualisation. Five Series, 200 Exp.				Without Visualisation. Five Series, 200 Exp.				With Eyes Open. Seven Series, 260 Exp.			
	Right.		Left.		Right.		Left.		Right.		Left.		Right.		Left.	
	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.
Peripheral	42	24.3	24	26	51	29.1	11	27.6	20	42.5	5	40.8	23	9.5	12	9.3
Central	2	6.5	3	19					4	22.5			87	8.2	1	9
Right	1	8	2	6	2	4			4	25	2	9.5	19	8.2	2	4
Left	5	22.5	13	18	1	17	4	23.3	4	25	16	32.2	1	8	2	11.3
Right Peripheral	14	16	10	14.4	25	28.8	5	24	29	56.5			35	7.6	8	8.2
Left Peripheral	51	21	68	22.3	20	21.7	77	23.9	15	31	71	42.1	14	6.5	57	9.1
Right Central	4	13.7							12	31.5			18	10.6	1	4
Left Central	8	10.5	5	12	1	15	3	14	12	25.6	6	24.6	13	11	27	13.5
Ratios of Cent. to Peripheral Displ.	.130	.500	.078	.494	.010	.188	.032	.060	.437	.612	.078	.296	.569	1.254	.298	.995
Ratios of Right to Left Displ.	.296	.685	.139	.139	1.227	.610	.059	.117	1.451	1.384	.021	.096	2.571	1.034	.127	.478

(5) In Table V we give the average error corrected as suggested by Mr. Pillsbury[1]. The values for the right and left arms are given separately, and then averaged. It may be noticed that in the case of *Py.* and *Mn.* the error is larger in the visual series than in the normal. This is probably due to the fact that both visualised normally, and when requested to make a distinct effort to do so, found the introspection necessary a distraction. *Py.* was so sure that he could not shut out visualisation that his somewhat larger average in the non-visual series seems best explained also by the distraction due to introspection and a strong effort to perform a difficult task. The difference between the average values in

TABLE V.

	UNIT = 1 MM.	RIGHT HAND.	LEFT HAND.	AVERAGE.
Py.	Normal	20.7	21.2	20.9
	With Visualisation	20.5	26.6	23.5
	Without Visualisation	27.02	30.6	28.8
	With Eyes Open	15.8	15.8	15.8
Mr.	Normal	23.6	43.5	33.5
	With Visualisation	21.7	36.4	29.0
	Without Visualisation	44.3	24.6	34.4
	With Eyes Open	28.0	17.9	22.9
Mn.	Normal	19.6	23.5	21.5
	With Visualisation	26.8	28.1	27.4
	Without Visualisation	45.3	41.5	43.4
	With Eyes Open	12.3	11.9	12.1
Ph.	Normal	23.8	33.3	28.5
	With Visualisation	24.9	23.9	24.4
	Without Visualisation	35.1	39.06	37.08
	With Eyes Open	16.9	15.6	16.2

[1] AMERICAN JOURNAL OF PSYCHOLOGY, VII, 1, pp. 43, 44.

the normal and non-visual series of *Mr.* is hardly greater than might be accounted for by mere chance.

The *great difference between the limina* as given by us in the Table and found by Mr. Pillsbury (AM. JOUR., VII, p. 51) is worthy of notice. In the experiments of the latter the subject moved about on the skin until the sensation was judged to be like that roused by the stimulus. In our work this normal ending of the localising movement was cut off. In the absence of a familiar group of elements (cutaneous sensations and visual associations connected with the second contact), recognition is not so easy as before, and, consequently, large errors are made in the judgment. Striking evidence of this was the fact that when the perpendicular was let fall from the point of localisation, the subject, as soon as the second contact was sensed, almost always recognised the direction of his error, and very frequently its approximate value. With some of the subjects there may have been a slight tendency to correct the direction of displacement ascertained in this way. In the case of the subject *Ph.* this source of error was eliminated by dropping the perpendicular after the metric rule was laid on the arm. When the experiment was tried of laying the metric rule on the arm after the stimulus, but before the localisation, the subject requested that it should not be done, since it effaced the impression to be localised.

B. GENERAL RESULTS.

An examination of the Tables will show that the displacements were mainly toward the wrist. Mr. Pillsbury gives as one important factor in the direction of displacement the overestimation of movements due to flexion when approached from extension, and the underestimation of those due to extension when the arm is much flexed, and quotes Loeb[1] in support of this view. The latter had explained the errors in estimation by the differences in extent of movement for the same amount of *innervation.* Mr. Pillsbury says, however: "It is not that equal innervation sensations correspond to equal lengths of movement, but that equal lengths of movement give greater amounts of motor sensations, and these are taken to mean greater distances on the visual space diagram." The fact that at least one subject in this investigation and one in Mr. Pillsbury's were able to shut out the visual space diagram in the act of localisation, would militate against the theory of any *constant* translation of motor sensation into visual

[1] *Untersuchungen über den Fühlraum der Hand.* Pflüger's Archiv, XLI, pp. 107-128. *Untersuchungen über die Orientirung im Fühlraum der Hand und im Blickraum. Ibid.*, XLVI, pp. 1-46.

space. Loeb thinks that movements in flexion, either with or without visualisation, give a greater amount of organic sensation than movements in extension of equal range when the arm is much flexed. A very simple introspection of ordinary experiences seems to make this evident. It may be, then, that the movement accompanying the greater amount of sensation is simply judged greater. Our normal judgment of distance, largely in terms of visual space, may have become so habitual that it will influence more or less any space judgment even under artificial conditions; but the fact that any form of a visual space diagram may be shut out and movements in flexion still be overestimated, may probably be interpreted to mean that a visual translation is not necessary. The results of this investigation, however, appear to confirm the general theory. The arm previously extended on the knee or hanging by the side was flexed in the act of localisation: the movements were overestimated, and the localisation fell short of the point stimulated. The arm resting on the chest, and in that position much flexed, was extended in the act of localisation: the movement was underestimated, and the localisation went beyond the point touched.

Table VI shows some results obtained from the various subjects with movements in extension.

Only a few experiments of this kind were made, as it was evident from the first that the results were of the same type as those in flexion. It may be noticed that there is not the same predominance of left over right displacements as in the preceding Tables. The small number of experiments would, of course, make any average a very crude one; but in any case the fact easily admits of explanation. The hand with which the localisation was made rested on the chest, approximately in the median plane. The movement concerned in localisation was largely a movement toward the front. The results are therefore significant mainly for peripheral and central displacements. For three of the subjects, however, "right peripheral" displacements predominate on the right arm and "left peripheral" on the left, a fact which is entirely in keeping with our theory of the underestimation of movements in extension.

The predominance of displacements to the left over those to the right on the right arm (see Tables I, II, III and IV) falls easily under our theory. This predominance is seen in all the subjects except *Mr.* The left hand in localising on the right arm stopped short of the point stimulated, as a result of the overestimation of movements in flexion. But on the left arm the left displacements are also dominant, and this seems to contradict our theory. Examination of the Tables, how-

TABLE VI.

Reactor: Py. Mr. Mn. Ph.

	Twenty Experiments.				Thirty Experiments.				Forty Experiments.				Forty Experiments.			
	Right.		Left.		Right.		Left.		Right.		Left.		Right.		Left.	
Unit = 1 mm.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.	No. of Displ.	Av. of Displ.
Peripheral	4	8	1	10	5	13	17	22.5	10	21.8	12	17.9	8	13.3	16	16.7
Central			1	6	2	7										
Right			4	7.9	3	9.3			5	12			10	17	2	11.5
Left	2	10	1	9					1	6	5	17.6	2	8		
Right Peripheral	2	11	8	10.6	18	14.9			16	15.3	4	15.4	8	16.8	9	16.1
Left Peripheral	12	20	2	6			13	18	6	25.6	19	14.9	7	13.6	13	13.3
Right Central			3	9	1	10			1	20			2	23		
Left Central					1	7			1	4			2	11.5		

ever, shows that these left displacements on the left arm are not so largely in the ascendency as on the right arm. Two influences were apparently at work. The right arm tended to make a greater excursion than the left, as will be explained hereafter, and so to pass beyond the stimulated point; but this tendency was counteracted in part by the influence of movements in flexion. It should be noted that in our work the movements of the right and left arms were made in series, and so were neither simultaneous nor immediately successive. The intervals between two series with the same arm were from ten to twenty minutes.

Loeb[1] describes some experiments which, though made for a different purpose, give substantially our conditions and are confirmatory of our results. His object in the special part of the investigation from which we quote was to show that in simultaneous movements of the hands in the same direction, the one moving laterally[2], the other medianly[3], and equal movements being intended, the median excursion is always greater than the lateral. In describing his work, Loeb says: "Die Versuchsperson steht wieder so vor dem Faden, dass derselbe ihre Medianebene im Kernpunkt unter einem rechten Winkel schneidet. Dagegen ist Ausgangspunkt der Fühlstrecken diesmal nicht der Kernpunkt, sondern je ein durch eine kleine Klemme markirter Punkt 200 mm. nach rechts und links vom Kernpunkte. Dieser Abstand entspricht beim erwachsenen etwa der Entfernung des adducirten Armes von der Medianebene; die linke Hand der Versuchsperson liegt an der linken, die rechte Hand an der rechten Marke. Der Faden ist wieder mit Daumen und Zeigefinger gefasst." He continues, and for his purpose this is the important point: "Die Aufgabe der Versuchsperson besteht darin, *gleichzeitig auf Kommando beide Hände nach derselben Richtung entweder nach rechts oder nach links bei geschlossenen Augen mit gleicher Geschwindigkeit zu bewegen.* Die Bewegung soll wieder so erfolgen, dass nach dem Urtheil der Versuchsperson der Abstand beider Hände vom Ausgangspunkt in jedem gegebenen Augenblick gleich ist. Die Bewegung soll sistiren, sobald die eine der beiden Hände an der vom Experimentator angesteckten Grenzmarke anlangt. Der Versuchsperson wurde gesagt, auf welcher Seite sie die Grenzmarke treffen wurde. Der Abstand war ihr aber unbekannt."

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[1] *Untersuchungen über den Fühlraum der Hand.* Pflüger's Archiv, XLI, pp. 116-119.

[2] Laterally = from the median plane outward.

[3] Medianly = from the side toward the median plane.

We have selected the "Mediale Fühlstrecke" from one of Loeb's typical series, and give the results :

LEFT HAND.	RIGHT HAND.
185	300
250	200
215	210
120	220
190	240

These "Mediale Fühlstrecken" were evidently obtained under conditions very similar to our own, as far as concerns the relative length of the excursion of the two hands ; and we find that the right hand made on an average a much greater excursion. From further experimentation by Loeb for the purpose of showing that it is important for the result whether the point which marked the limit of the excursion of one hand lay on the lateral or median side of the axillary line, we can again compare the "Mediale Fühlstrecke" when this mark lay on the lateral side. The excursion of the right hand is here, too, larger than that of the left. The explanation of this, since it is not entirely germane to our discussion, we reserve for an appendix.

It will be noticed that for all the reactors there were some central displacements. The introspection of one of them showed that in some of these cases there was inattention, and consequently random localisation. Observation on the part of the experimenter showed that there were now and then accidental changes of position which brought the arms into such relation that *less* movement in flexion was necessary to make a central than a peripheral displacement. Some centrals were, no doubt, due to absolute chance. In the experiments with the eyes open, central displacements are more numerous than elsewhere. Nearly all of these occurred in the earlier series. There was probably confusion resulting from the failure, at first, to translate into the more extended visual space, now introduced quite importantly, the cutaneous space which was predominant in the non-visual experiments. The visual extension from wrist to stimulus-point, obtained when the eyes were open, would be likely to bring about an overestimation of the movement centred necessary for localisation. Some of the smaller central displacements were obtained as vacillations of the hand after localisation. There seemed to be indifference of localisation within certain limits, the hand often wandering about a more or less circular area with a radius of perhaps 4–10 mm., though no attempt was made to determine it exactly.

The average displacement for all the subjects is smallest with the eyes open. For two of them, that for the non-visual

series is the largest. Visualisation apparently lessens the amount of displacement. The visual factor being now given a place in combination with the other factors concerned in localisation, the constant error is smaller.

C. Summary.

(1) The displacement toward the wrist found in these and the related experiments of Mr. Pillsbury seems to be due to *overestimation of movements in flexion and underestimation of those in extension.* We have suggested in explanation of this that as flexion, approached from extension, gives a greater amount of organic sensation than extension, approached from flexion, the *amount of sensation* is in the one case judged a greater, in the other case, a smaller distance.

(2) When the normal ending of the localising movement (pressure upon the skin) is cut off, *the limen of localisation is much greater.* We have explained this by showing that the removal from the total experience of one or a number of familiar elements, artificially or otherwise, makes recognition more difficult, and that this difficulty of recognition is expressed in a greater error of localisation.

(3) *With visualisation the amount of displacement is lessened.* This greater accuracy results, in general, from the emphasising of a factor which, in ordinary experience, is very influential in tactual localisation.

(4) In movements not simultaneous, for distances estimated as equal, *the right arm tends, for movement in flexion, to make greater excursions than the left.* (Cf. Appendix.)

D. Appendix.

Before attempting to suggest even a tentative explanation of the tendency of the right hand (as found in these experiments) to make the greater excursion, it would, perhaps, be better to give the evidence for it as found here and elsewhere. In this investigation, three of the subjects show the tendency. Some crude experimentation in the general drill-work of the Cornell laboratory showed in the case of a large majority of the eighteen subjects a slightly greater excursion of the right hand than of the left. An arrangement of Loeb's tables, so as to bring them approximately under the same conditions as our own, tends to confirm our results. In the experiments mentioned above, however, the movements were made from the side toward the median plane. They were movements in flexion. The question arises as to which arm would make the greater excursion when moving from the median plane outward—movement in extension. The drill-experiments in the labor-

atory showed that for the majority of the subjects, the *left* hand made the greater excursion in the movements last described. In the table given by Loeb (p. 110 of article previously quoted) we find a greater excursion for the *right* hand, when moving from the median plane outward, for four out of six subjects. On pp. 112 and 113, the greater excursion is shown for the right hand in the case of three out of four subjects; yet it must be remembered that Loeb quoted results which were typical as regards his own question, and that they were not selected with any reference to ours. On p. 114 of the same article he says, with reference to movements from the median plane outward, that for right-handed persons, not mechanics, the *left* hand makes the greater excursion. Sanford[1] makes, tentatively, a similar assertion. Hall and Hartwell[2] experimented upon a large number of subjects, but chiefly upon two right-handed and two left-handed persons. They say that in simultaneous movements from the median plane outward, the "preferred hand" made the greater excursion. However, when the movements were successive instead of simultaneous, there was a tendency to reduce the excess of the preferred hand, and, *in some individuals*, to make an equal or even a greater error in favor of the non-preferred hand.

It is, perhaps, well to note that Mr. Pillsbury[3] found in all of his subjects a tendency to a larger number of peripheral displacements when localising with the right hand than with the left. This would seem to indicate that the left hand made the greater excursion in movements toward the median plane. In our own experiments two of the subjects have similar and two have contrary results. However, as has already been hinted, the exact position of the arm operated upon, relatively to the other, would materially affect the interpretation of these results, and this position was not regulated with any reference to our present question, either in the experiments of Mr. Pillsbury or in our own.

That there are inconsistencies and apparent contradictions in the outcome of the investigations just quoted, is not surprising. None of them, except those of Hall and Hartwell and the drill-work of the Cornell laboratory, were conducted with any view to Bilateral Asymmetry of Function. A large number of factors other than those affecting the question at issue would enter into such experimentation, and would, to a greater or less degree, vitiate the results for our purposes. Yet there are in them some suggestions. Hall and Hartwell

[1] "Laboratory Course in Psychology," p. 35.
[2] "Bilateral Asymmetry of Function," *Mind*, O. S., IX, pp. 93-109.
[3] AM. JOUR. OF PSYCHOL., VII, p. 52.

say that the right arm is sometimes one-third stronger than the left. Loeb and Sanford agree that, in the case of mechanics, the right arm makes the greater excursion. This may point to a loss of sensation (automatism, lapse of attention) due to habituation; the less noticeable amount of sensation being judged the smaller distance, the right hand would move too far. We find in the various results quoted some indication that with right-handed persons, not mechanics, the right hand makes the greater excursion for movements in flexion, but the left hand for movements in extension. This might also be explained upon the assumption of loss of sensation due to habituation. The movement of the right hand in flexion, though still giving distinct sensations and requiring effort, is underestimated as compared with that of the left, because the right hand, being used more frequently, has been reduced to a greater degree of automatism. In movements of extension, *i. e.*, from the median plane outward, the movement is one of relaxation, the sensations caused by the flexion being lost as the hand moves outward,—at least, through small distances. Since, when both hands are held in the median plane, less sensation results from the flexion of the right arm than from that of the left, there is less to be lost in the outward movement, and the right hand does not go so far as the left. We admit, however, that this, the only explanation which we can now offer, is not very satisfactory, and that it applies, in any case, only so far as the outward movement is a relaxation of tension.

The mixed results before us can be, at best, only suggestive. Continued and careful experiments upon a large number of subjects under conditions from which, as far as possible, all factors except those directly affecting the relative movements of the two arms have been eliminated, would be necessary to give sufficient data for any definite theory. Indeed, it may be true, as suggested by Sanford in connection with the same subject[1], that the judgments of symmetry of position and motion rest upon such complex combinations of cutaneous and organic sensations that the results will always be variable from one subject to another and in the same subject at different times. There must, however, be conditions for this variation, and the complexus of sensations may not be able to resist all analytical attacks.[2]

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[1] *Op. cit.*, p. 36.

[2] Experiments upon this question are now in progress in the laboratory of the Randolph-Macon Woman's College.